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Method and Device for Atomizing Metal Melts

The invention relates to a method for atomizing metal melts, in which the liquid metal bath is sprayed from a tundish via an outlet opening by the aid of a gas into a cooling chamber, or onto a surface to be coated while compacting the comminuted particles by the aid of a propellant gas, as well as a device for carrying out said method.

In order to obtain dense metal coatings, it has already been proposed to eject such metals from a melt bath by the aid of propellant gases onto a surface to be coated or any other target with the still molten droplets solidifying during impingement on the surface to be coated or any other target (substrate), thus causing the coating to be accordingly compressed or compacted. When atomizing molten metals by the aid of propellants, an inert propellant gas jet is usually employed at ambient temperature, the known processes all requiring a relatively high propellant gas consumption and, as a rule, also a relatively high propellant gas pressure. A number of nozzle geometries have been proposed for the atomization and compaction of such atomized metal particles. The economy of such methods, as a rule, has, however, been substantially determined by the propellant gas amount and propellant gas pressure required.

The invention aims to provide a method of the initially defined kind, by which it is feasible to atomize molten metals efficiently and by using substantially smaller-structured devices while substantially lowering the necessary amount of propellant gas, whereby a substantially finer atomization is to be ensured and the option to incorporate also other components into the atomized metal melt is to be provided, at the same time. To solve this object, the method according to the invention essentially consists in that the liquid metal melt via an annular gap is introduced into the outlet opening, into which a hot gas having a temperature of between 250°C and 1300°C and a supercritical pressure of between 2 and 30 bars is ejected through a Laval nozzle concentrically with said

opening, and that the hot gas is contacted with the melt bath at a speed exceeding supersonic speed, with a radial outwardly directed component or with a twist. By using hot gases having temperatures of between 250°C and 1300°C and a supercritical pressure of between 2 and 30 bars as opposed to the known methods, the viscosity of the propellant gas is substantially increased in view of known methods, whereby shearing forces will act more efficiently and a finer comminution of the metal melt into particularly small particles having diameters d_{50} of below 10µm will be obtained. At the same time, it is feasible to reduce the propellant gas consumption to 1/3 to 1/5 as against the use of propellant gases at the usually low temperatures, thus yielding substantial advantages as regards the economy of metal pulverization processes. Another advantage consists in that the metal melt does not freeze in the melt runout due to smaller temperature differences. By introducing the liquid melt via an annular gap into the outlet opening it has become feasible to influence the inflow of liquid melt and hence the flow rate per time unit in a simple manner by an appropriate adjustment of said annular gap, and by introducing the propellant gas concentrically with the outlet opening it has become feasible to use the structural component defining the annular gap as a second concentric tube, i.e., as a suction tube to suck in further substances. By contacting the hot gas with the melt bath at a speed exceeding sonic speed with a radial outwardly directed component or with a twist, which is feasible, in particular, by effecting the ejection under a supercritical pressure via a Laval nozzle, it is feasible to transmit high shearing forces at reduced propellant gas amounts, thus ensuring a particularly efficient and rapid comminution during the impingement on the metal melt by rapidly braking the propellant gas jet, which is more highly viscous on account of the elevated temperatures. By the hot gas being ejected in the interior of the melt jacket and contacted with the melt bath with a radially outwardly directed component, the gas is forced to pass through the melt jacket, thereby tearing the melt jacket open. This definitely brings about an essential advantage, which resides in the formation of a monograin

powder, which formation is promoted by the radial tearing open of the hollow-cylindrical melt jacket. As the melt jacket is being torn open radially, it causes the formation of a uniform ligament in the radial direction and, after this, extremely uniform droplets. The monograin powder is excellently suitable for use in powder-metallurgical processes.

The flow conditions of the hot gas streaming out through the Laval nozzle may also be adjusted in a manner so as to form an underexpanded propellant jet. This will subsequently result in pressure bursts in the range of Mach's nodes with expansion volumes lying between such Mach's nodes. Due to vibration interferences in the jet, shearing stresses will be introduced into the melt droplets, thus causing a rise in frequency with supercritical conditions increasing and a respective reduction of the distances of Mach's nodes in the axial direction of the propellant gas jet. The fact that an underexpanded jet is ejected causes an immediate expansion after the emergence from the nozzle. In a configuration of this type, the distance to a surface to be coated may be chosen to be extremely short such that small-structured devices will do. Advantageously, the hot gas is ejected through a deflector body so as to enable the effective cross section of emergence from the Laval nozzle to be adapted to the respective requirements by a suitable adjustment of the deflector body. The use of a deflector body also serves to impart on the outflowing hot gas an appropriate additional flow component directed radially outwards and/or a twist.

Advantageously, the method according to the invention is realized in a manner that a lance comprising the Laval nozzle for the hot gas is conducted concentrically in a tube while forming an annular space, and that reactive gases such as, e.g., CO, H_2, O_2 or H_2O vapor, and/or inert gases such as, e.g., N_2 or Ar, and/or carbides such as, e.g., WC, TiC or VC, are sucked in via said annular space. The tube surrounding the lance with the Laval nozzle, by its lower edge defines the annular gap required for the access of the liquid metal melt, while an annular space is, at the time, formed between the

lance and the tube for the aspiration of reactive gases and/or inert gases. Such a configuration allows for a preferred method control, by which metal powders or additives such as, e.g., SiC, Al_2O_3 or Y_2O_3 and/or carbides are charged into the aspirated gas flow, thus ensuring a high degree of adjustability of the atomizing process to different requirements by means of a particularly simple structural configuration of the device.

The radiation heat of the metal melt ejected by the hot propellant gas and effectively atomized during ejection may be used to heat the hot gas, to which end it is preferably proceeded in a manner that the hot gas is heated in a heat exchanger surrounding the melt particles ejected.

By using a hot gas, particularly small particles are formed as pointed out already in the beginning, thus leading to the formation of a flow of extremely fine particles, which is directed outwardly in a vortex-like manner, in the cooling chamber besides a downwardly directed flow. These extremely fine particles are again sucked into the downwardly directed flow of atomized melt, where they partially serve to rapidly cool the atomized melt. In order to reduce the portion of extremely fine particles which are effective for cooling, yet partially impede the efficient comminution of the particles, and, in particular, in order to ensure that such extremely fine particles will not cause caking in the region of the outlet opening or mouth of the tundish, it is advantageously proceeded in a manner that extremely fine particles of the solidifying melt, which ascend within the cooling chamber, are sucked off below the entry of the melt flow and discharged via a sluice. The option to suck in additional solid substances such as, for instance, silicon carbide, Al_2O_3 or Y_2O_3 in fine-powder form via the annular space, also allows for the obtainment of metal - matrix composite materials as well as ceramic - metal composite materials, and hence particularly wear-resistant coatings. Unlike with complex-design discrete spray nozzles, it is feasible by means of a single Laval nozzle and a consecutively arranged deflector body via which

merely the hot propellant gas is ejected, to take into account all the set objects at a substantially reduced fuel consumption, the only thing required, in detail, being the appropriate adjustability of the tube to adjust the annular gap as well as the appropriate selection of the aspirated gases. Furthermore, the desired jet geometry may be influenced, and adapted to the selected substances, in a simple manner by an appropriate axial displaceability of the hot gas nozzle, or of the deflector body, and/or an appropriate exchange of the deflector body. In the main, the process control according to the invention renders feasible the efficient atomization of any sort of metal melts while also enabling the atomization of alloys and, in particular, ferroalloys such as, for instance, FeV, FeCr, FeW, FeTi or FeMo.

According to a preferred process control, a pressure of 1.5 to 25 bars may be maintained within the tundish, while a pressure of 1.5 to 10 bars is preferably maintained in the cooling chamber. By observing these pressure levels, a melt saturated with pressure gas will be obtained, the pressure gas being comprised, for instance, of argon. The melt saturated with pressure gas facilitates disintegration, thus enabling an altogether finer atomization. The introduction of gas may be effected by means of bottom tuyeres of the tundish or via an immersion lance.

The device according to the invention for carrying out said method includes a melt tundish and an immersion tube immersed in the melt while forming an annular gap surrounding the outlet opening for the melt, wherein a lance is further provided for the ejection of a propellant gas. The device according to the invention is essentially characterized in that the height-adjustable lance carries a Laval nozzle, wherein a deflector body is preferably arranged in a height-adjustable manner in the widening opening region of the Laval nozzle or following thereupon, viewed in the flow direction, the clear cross section between the nozzle and the deflector body being designed to increase in the axial direction towards

the outlet end and to be larger than the narrowest cross section of the Laval nozzle. The deflector body provided in the widening opening region of the Laval nozzle, or following thereupon, viewed in the flow direction, may be adjusted on account of its height adjustability with a view to minimizing the consumption of propellant gas, wherein, in order to obtain the desired supersonic speed, it merely has to be taken care that the clear cross section between the inner wall of the Laval nozzle and the deflector body is designed to be always larger than the narrowest cross section of the Laval nozzle in the axial direction towards the outlet end and to increase in the axial direction. The arrangement of a deflector body is, however, not necessarily required, and it has turned out that an efficient atomization is feasible also without deflector body, particularly favorable results being achieved if, as in correspondence with a preferred further development of the device according to the invention, the lance opens in the outlet opening of the tundish below the lower edge of the immersion tube. To this end, the lance is arranged to be adjustable in height.

In order to obtain an annular space suitable to suck in additional components, the configuration advantageously is devised such that the outer diameter of the lance is smaller than the clear diameter of the immersion tube and the lance is sealingly guided through a lid of the immersion tube, and that a duct for the supply of gases and/or reactive metal powders and/or additives opens into the space of the immersion tube surrounding the lance. An adjustable throttle valve may be provided in the duct intended to supply gases and/or reactive metal powders, so that the volume between the lance and the immersion tube may optionally be maintained under a suitable negative pressure, pulsating flows, thus, being additionally obtainable. It is, however, also feasible to keep the valve completely closed.

Advantageously, the deflector body is designed as a cone having deflector surfaces provided on its jacket. A distinctive radial component may be achieved by means of such

a deflector body if, as in correspondence with a preferred configuration, the deflector surfaces extend in an S-likely curved manner and, in the peripheral direction, terminate so as to be directed at the tangent of the base circle of the conical body each under the same angle.

In the following, the invention will be explained in more detail by way of an exemplary embodiment of a device suitable to carry out the method according to the invention, which is schematically illustrated in the drawing.

In Fig. 1, a melt tundish 1 in which a metal bath 2 is kept in the molten state is illustrated in cross section. In order to keep this metal bath in the molten state, an inductive heating may be provided, as is schematically indicated by coils 3.

A tube 4 is immersed in the metal bath, defining an annular gap between the bottom of the tundish 1 and the lower edge of the tube. This tube 4 is adjustable in the height direction in the sense of double arrow 5 so as to allow the amount of metal bath flowing off the tundish 1 per time unit to be regulated in a simple manner.

The tube 4 is closed by a lid 6 in which a lance 7 is sealingly conducted in the sense of double arrow 8 so as to be adjustable in height. On its outlet end for hot gas, the lance 7 comprises a Laval nozzle 9. By virtue of this configuration as a Laval nozzle, sonic speed will exactly adjust in the narrowest cross section of the Laval nozzle 9 if hot gas is supplied under supercritical conditions, supersonic speed being reached in the consecutive widening cross section on account of the rapid expansion occurring. In this widening region is arranged a deflector body 10 which is also adjustable in the axial direction in the sense of double arrow 12 via an appropriate rod assembly 11. Suitable adjustment of the deflector body may, thus, influence the jet shape, whereby it merely has to be safeguarded that the respectively effective cross section widens accordingly in the axial direction following the narrowest point of the Laval nozzle 9

so as to ensure the attainment of supersonic speed caused by the rapid expansion.

The propellant gas jet emerging from the lance 7 then reaches a consecutively arranged cooling chamber 13, in which a target 14 may, for instance, be provided. The propellant gas jet collides with the outflowing metal bath at supersonic speed and an appropriate viscosity on account of its high temperature so as to effect rapid and efficient comminution, which may be applied to the target 14 as a coating. In the absence of such a target 14, the appropriately comminuted metal powder may be drawn off the cooling chamber 13 via a sluice 15 provided on its lower end. The radiation heat of the solidifying metal droplets may be exploited in a heat exchanger 16 surrounding the cooling chamber, to which cold gas is fed through a duct 17 and from which hot gas is drawn off through duct 18. If the thus obtained temperature is sufficient for the desired purposes, this hot gas may be directly fed to the lance 7 via duct 18. Further heating may be obtained by the aid of conventional recuperative heat exchangers not illustrated in the drawing.

In the interior of the cooling chamber 13, a further annular duct 19 is to be seen, via which extremely fine particles may be sucked off. These extremely fine particles may be supplied to a screening means 21 through a duct 20 and discharged as an extremely fine powder through a sluice 22. The amount of extremely fine powder discharged, thus, will no longer get into the downwardly oriented flow and have no influence on the solidification behavior of the droplets comminuted by the propellant gas jet.

The lance 7 is guided at a distance from the inner wall of the tube 4, leaving free an annular space 23. Additional material may be sucked into this annular space via a duct 24, said additional material comprising, above all, reactive gases like CO, H_2, N_2, O_2 or, if a partial oxidation of the metal particles is sought, also H_2O vapor. The amount aspirated in each case may be determined by the aid of an adjustable

throttle valve 25. A number of powdery materials capable of flowing along with a gas stream may also be sucked into this duct from a reservoir 26 as doping agents. As dispersible solids, metal powders, SiC, Al_2O_3 or even Y_2O_3 may, above all, be aspirated and introduced via duct 24 into the annular space 23, from which they are aspirated via the hot gas stream and rapidly brought into intensive contact with the metal melt.

Fig. 2 depicts a modified configuration of the propellant gas lance, in which the lance 7 opens in the outlet opening of the tundish 1 below the lower edge of the immersion tube 4. The lance comprises a Laval nozzle 9, whereby the arrangement of a deflector body may be obviated. Attempts have shown that the atomization results are the better the deeper the propellant gas nozzle is inserted into the melt runout.

Inert gases such as, for instance, nitrogen, argon and helium may, be envisaged as propellant gases in the first place, yet also reactive gases like CO, H_2, optionally blended with water vapor, may be used depending on the set object, if an oxidative atomization is sought.

Metal melts may comprise Al, Cu, Fe, Ni, Co, Ti, Mg melts or melts of rare earth metals or alloys thereof and, in particular, Co-based superalloys. The powders obtained are particularly suitable for applications in powder metallurgy, for instance for hot isostatic pressing, but also as a charging material for MIM processes (metal injection molding).